MC study of 2km muon range detector for JHF neutrino experiment

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Outline

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- MRD
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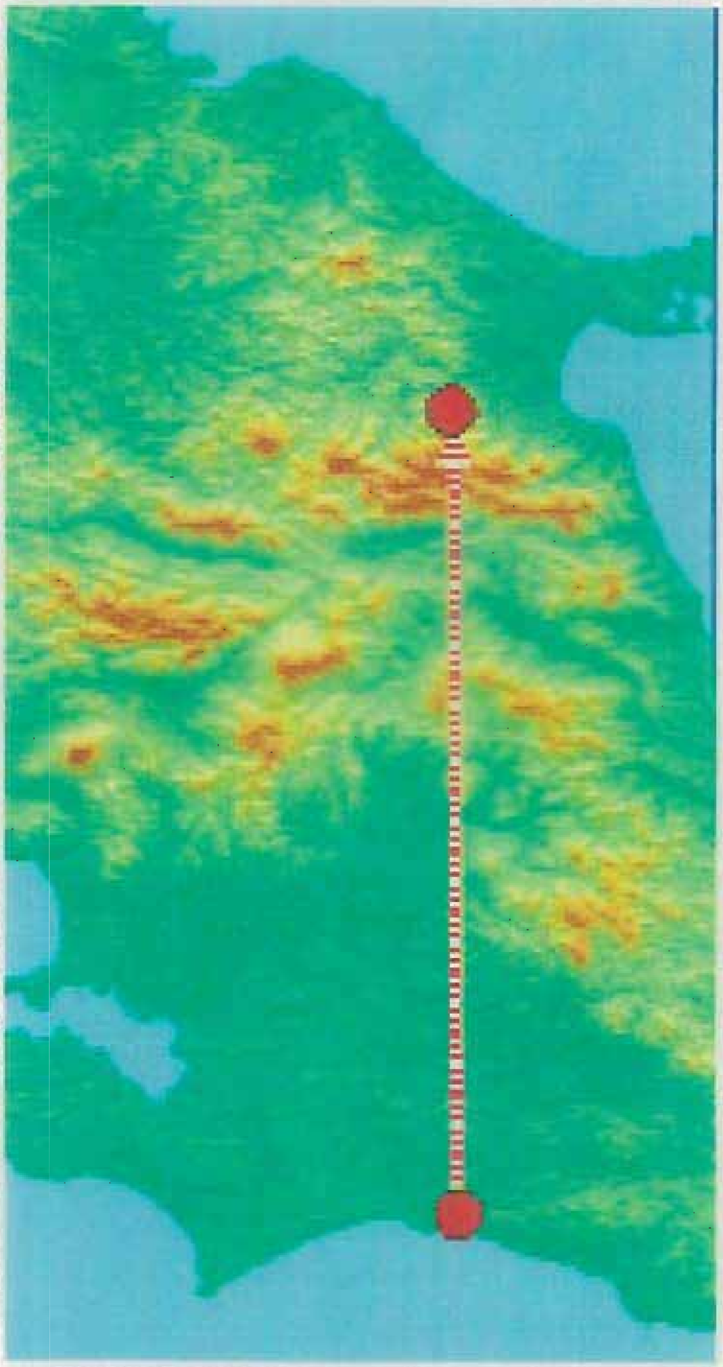
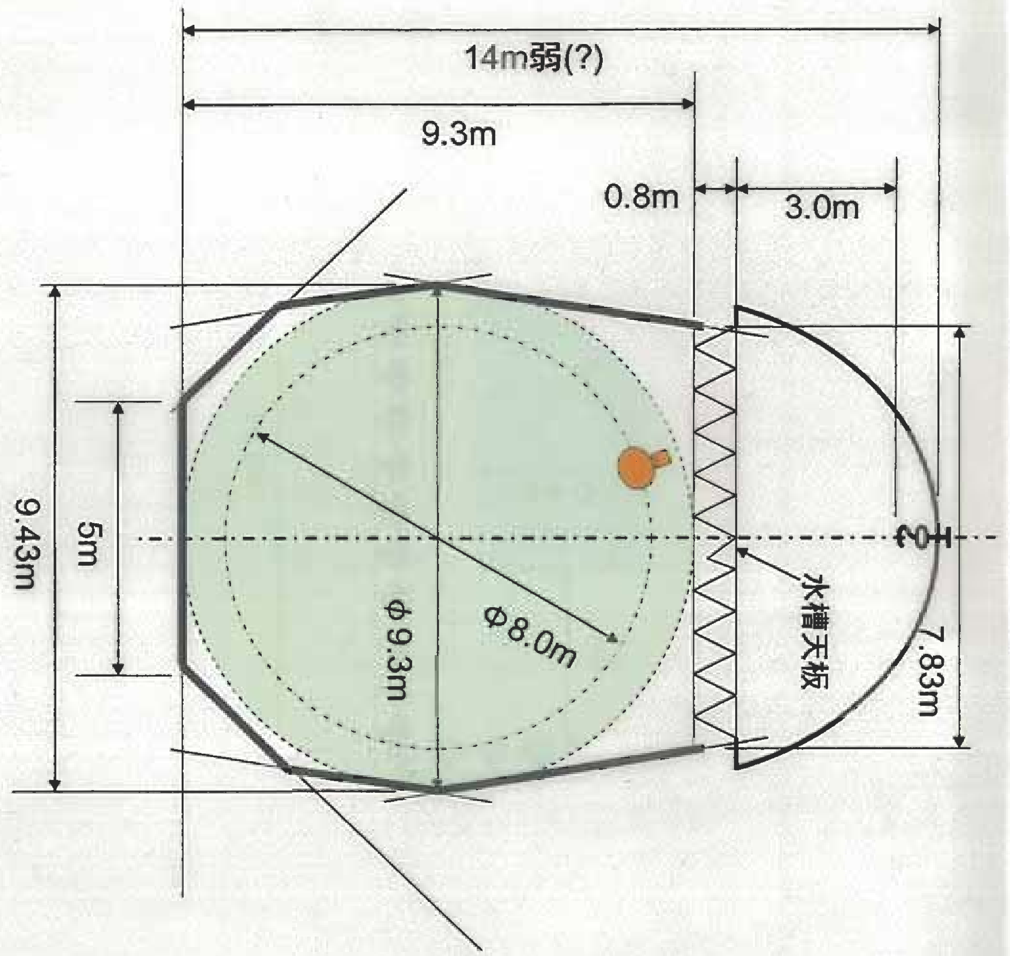
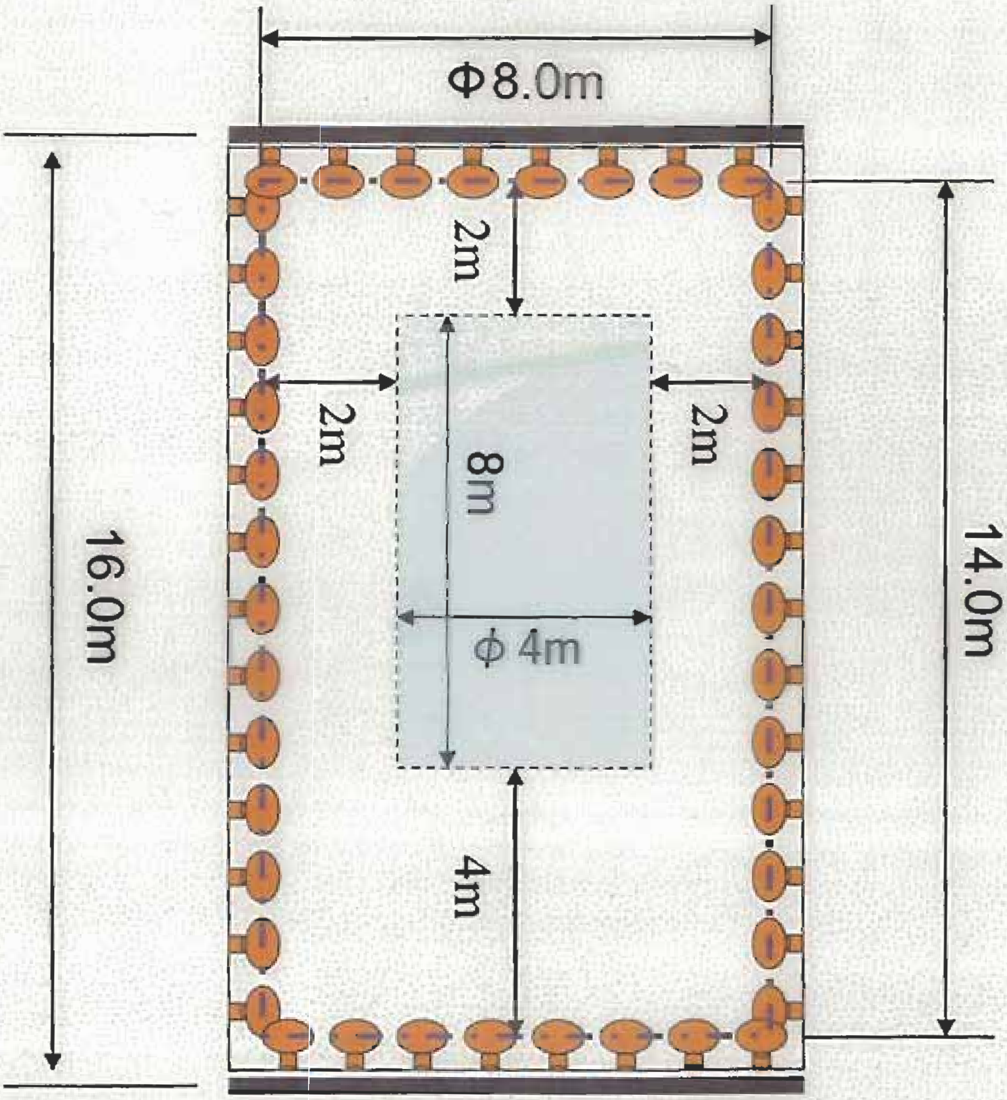
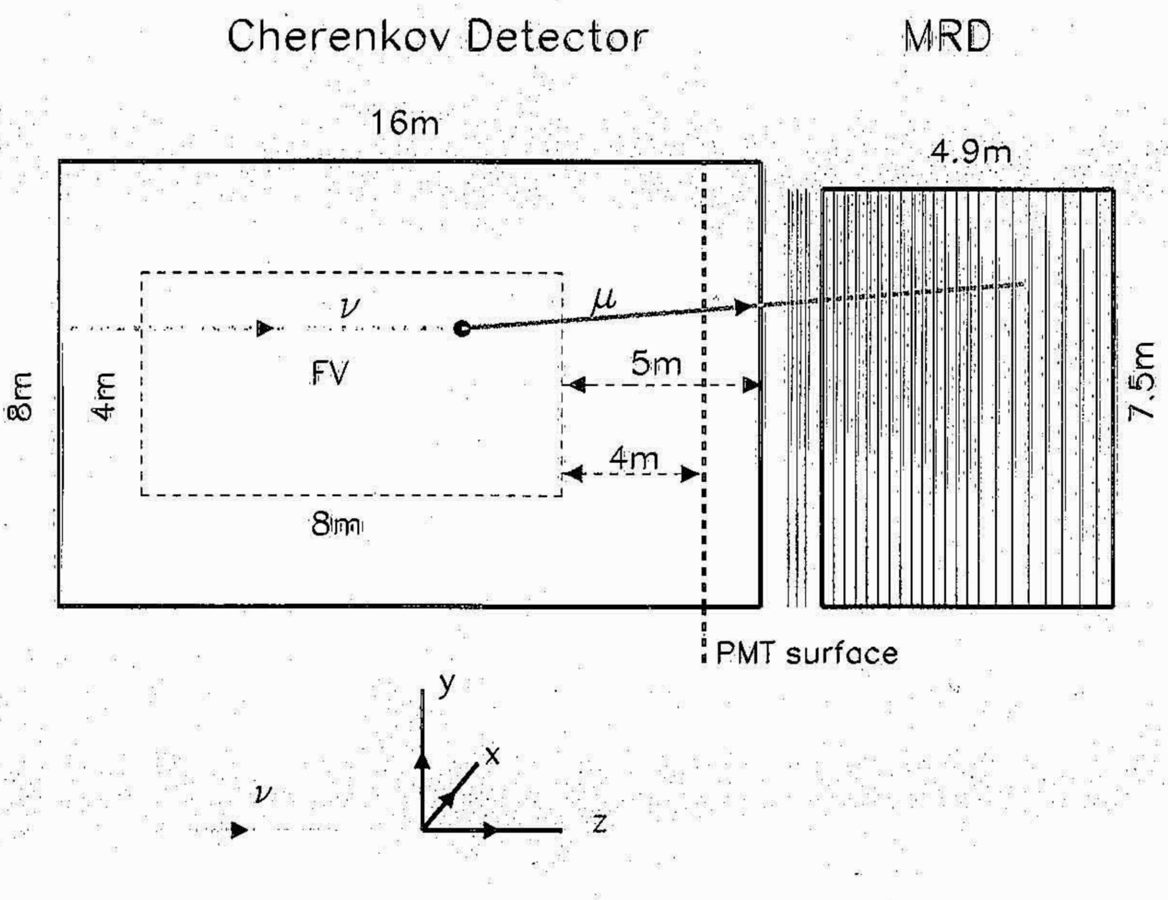
  - Design
  - Muon track reconstraction
  - Resolutions
- Cherenkov detector + MRD
  - Reconstarction efficiency
  - Resolutions
- Concluding remarks





14m弱(?)
9.3m
0.8m
3.0m
9.43m
5m
φ9.3m
φ8.0m
水槽天板
7.83m


Φ8.0m
16.0m
14.0m
2m
2m
2m
8m
φ 4m
4m



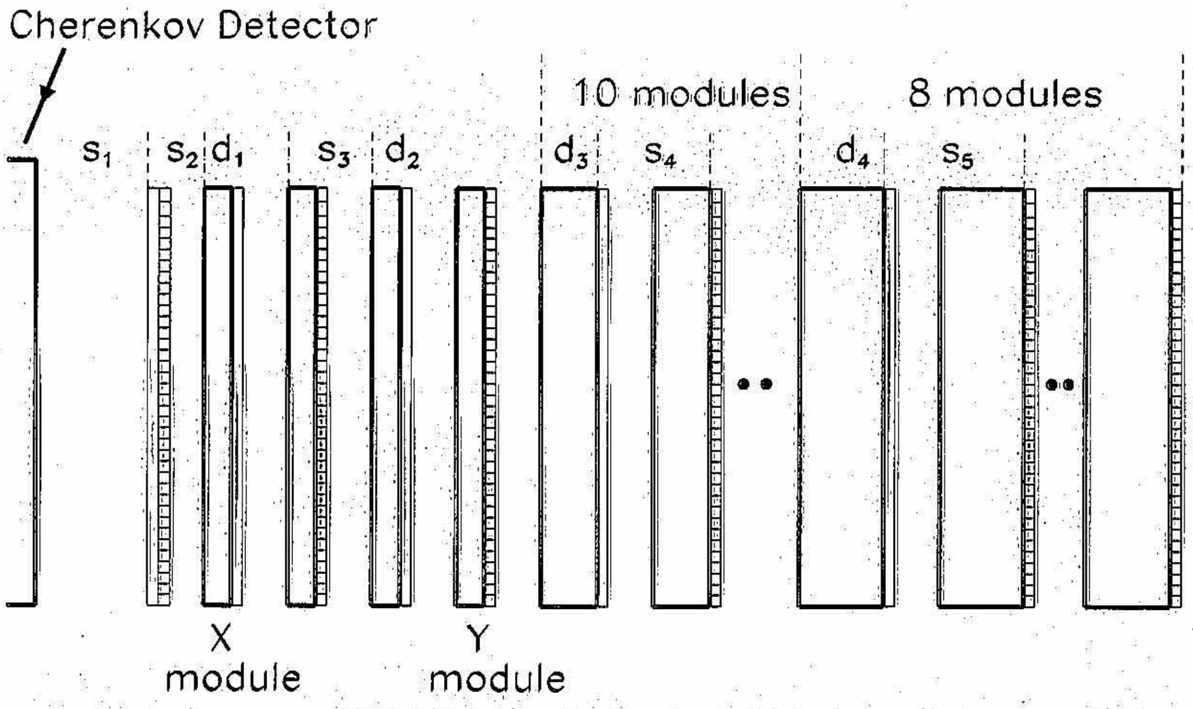
Cherenkov Detector
MRD
16m
4.9m
ν
μ
FV
5m
8m
4m
4m
8m
7.5m
PMT surface
y
x
ν
z

Requirements of MRD

- Low energy threshold
- Good energy resolution for wide muon energy region
- High reconstarction efficiency
- Size can't be more than 5m length, 8m width and high

MRD Side View

24 scintillator modules and 22 steel planes



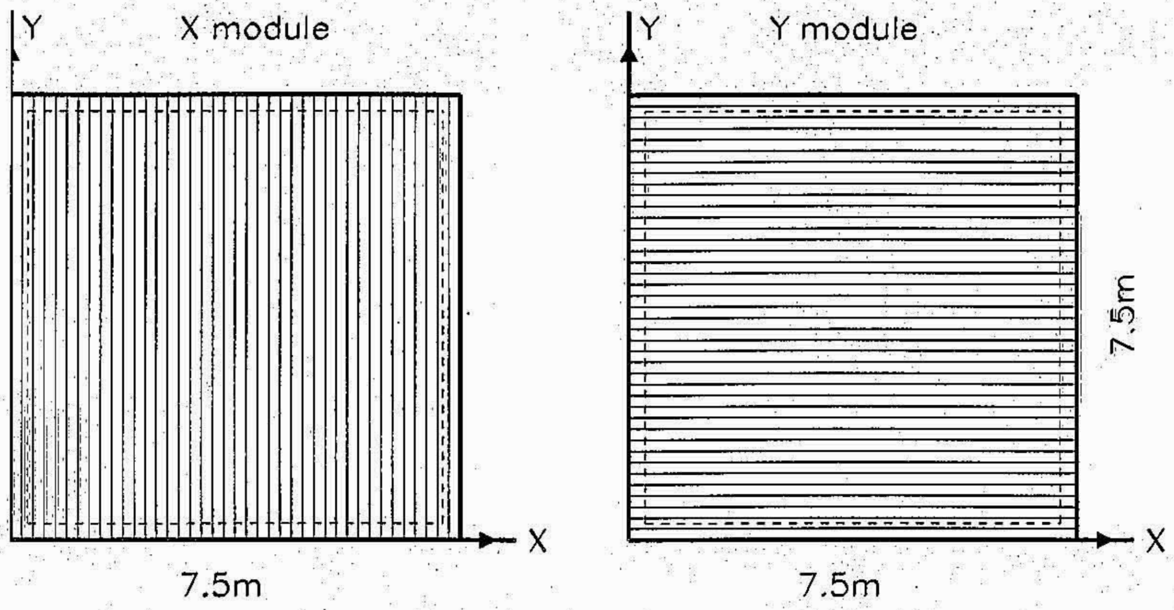
Thickness of steel planes

MRD2 d_1=5cm, d_2=5cm, d_3=10cm, d_4=20cm, H=2224g/cm^2

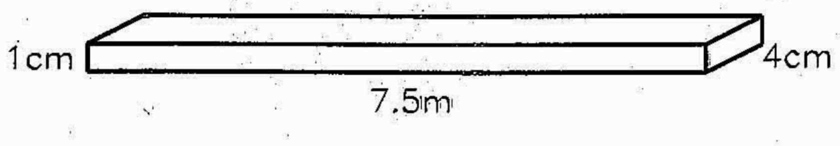
MRD3 d_1=2.5cm, d_2=5cm, d_3=10cm, d_4=20cm, H=2185g/cm^2

s_1=74cm, s_2=11cm, s_3=19.1cm, s_4=19.1cm, s_5=29.1cm

Scintillator modules



187strips/module



Muon tracking in MRD: linear fit

- A reconstructed track (x_i, y_i)
  $x_i = x_0 + b_x(z_i - z_0), \quad b_x = \left(\frac{P_x}{P_z}\right)_0$
  $y_i = y_0 + b_y(z_i - z_0), \quad b_y = \left(\frac{P_y}{P_z}\right)_0$
  (x_0, y_0) - track origin
  (b_x, b_y) - slop of the track in xz and yz planes at its original

- Least squares method
  $\chi_x^2 = \Sigma_{i,j}(x_i^m - x_i)w_{ij}(x_j^m - x_j),$
  $\chi_y^2 = \Sigma_{k,l}(y_k^m - y_k)w_{kl}(y_l^m - y_l)$
  x^m, y^m - the measured value of track position

- Weight matrix
  $[w_{ij}] = [V_{ij}]^{-1}, \quad V = V_{er}(\epsilon) + V_{ms}(P)$
  $[V_{ij}]$ - covariance/error matrix
  The uncertainties arise from limitations in the measurement accuracy of the detectors and from errors induced by multiple scattering.

- **Measured errors are taken into account by a diagonal matrix** $[V_{ij}]_{er} = \epsilon^2 \delta_{ij}$
$\epsilon = r/\sqrt{12}$, **r=4 cm is strip's width.**

- **Multiple scattering matrix take into correlation between measurements**
$[V_{ms}]_{ij} = \langle P_i P_j \rangle$.
$\langle P_N^2 \rangle$ **- variation in displacement at plane** N
$\langle P_K P_N \rangle$ **- covariance between the displacements at planes** K **and** N

- $\langle P_N^2 \rangle = \Sigma_{i=1}^N \theta_{0i}^2 (\frac{x_i^2}{3} + D(i,N)(x_i + D(i,N)))$

$\langle P_N P_K \rangle = \Sigma_{i=1}^K \theta_{0i}^2 (\frac{x_i^2}{3} + \frac{x_i}{2}(D(i,K) + D(i,N)) + D(i,K)D(i,N))$,

x_i **and** $D(i,k)$ **are width of steel and the distance from plane** i **to plane K along the path of muon**

- **Mean square scattering angle at the i-th plane**

$$\theta_{0i} = \frac{\theta_0}{1-\sum_{j=1}^{i}(dE/dX)x_i/p_0}$$

dE/dX **is the muon energy losses,** p_0 **is an initial muon momentum in GeV**

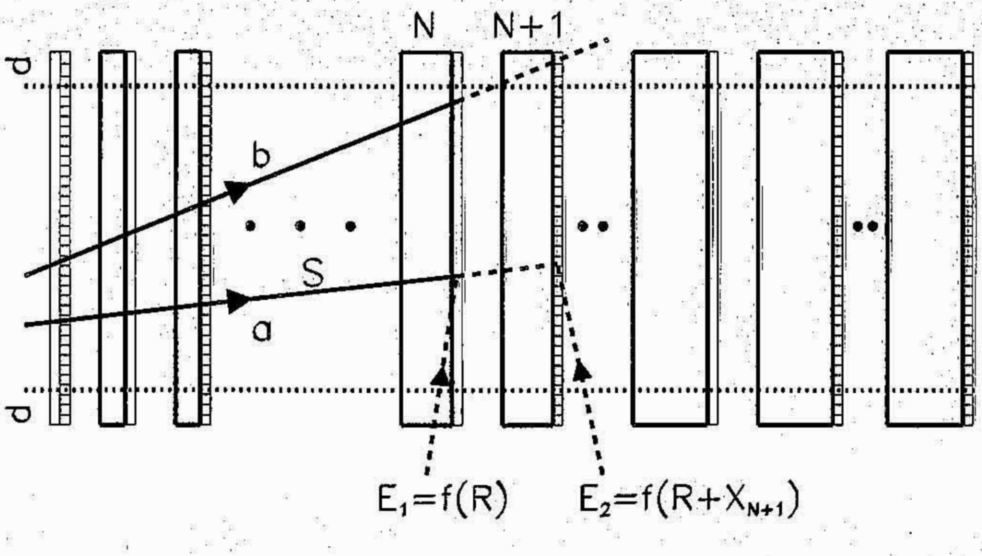
$$\theta_0 = \frac{0.0136}{p_0\beta}(\frac{x_i}{X_0})^{1/2}[1 + 0.038\ln(\frac{x_i}{X_0})]$$

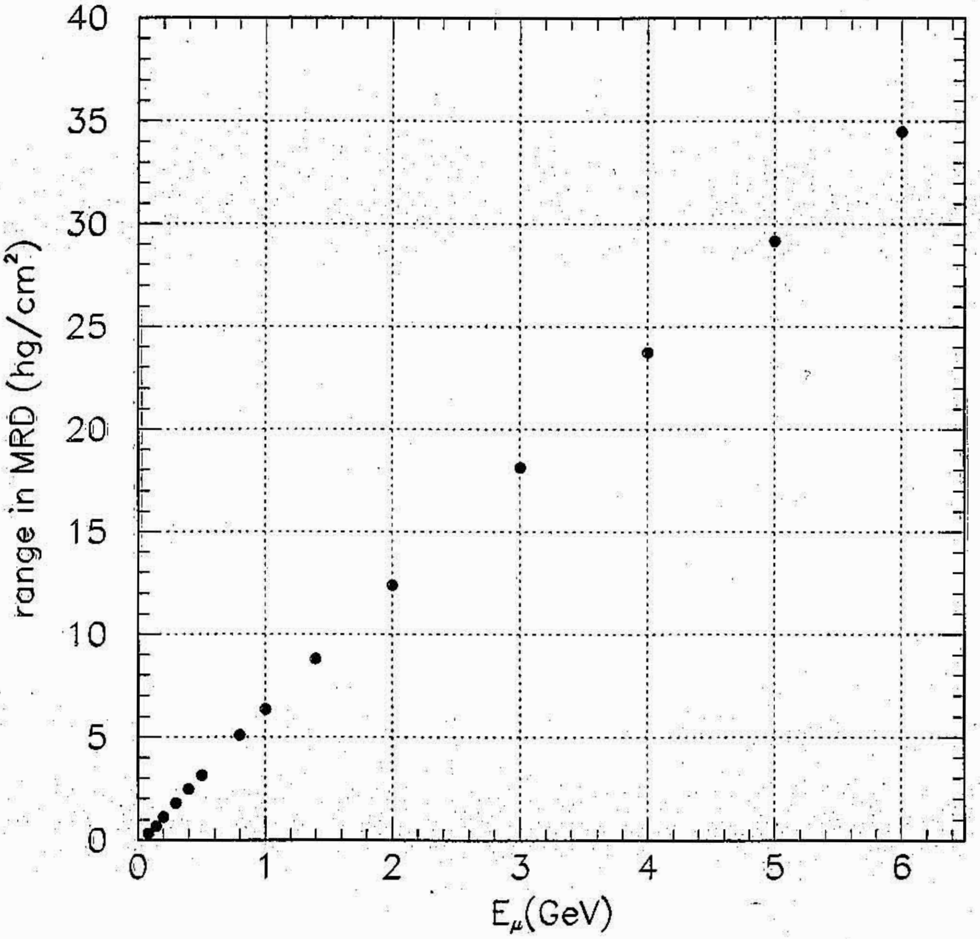
X_0**=1.76 cm - radiation length of iron**

MRD: Muon track and energy reconstraction

- Number of the hitted scintillator planes $4 \leq N_h \leq 23$, the track parameters x_0, y_0, b_x, b_y and track length S are calculated using $V = V_{er}(\epsilon)$
- Energies $E_1(S)$ and $E_2(S + X_{N+1})$ are evaluated and the muon energy is estimated as $E_{rec} = (E_1 + E_2)/2$
- **Repeat with $V = V_{er}(\epsilon) + V_{ms}(P)$, using the reconstructed track direction and energy E_{rec} for calculation of V_{ms} matrix.**
- **Containment analyses requires a track to be contained in detector to make an energy measurement possible.**

MRD Side View





range in MRD (hg/cm²)
E_μ(GeV)
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6

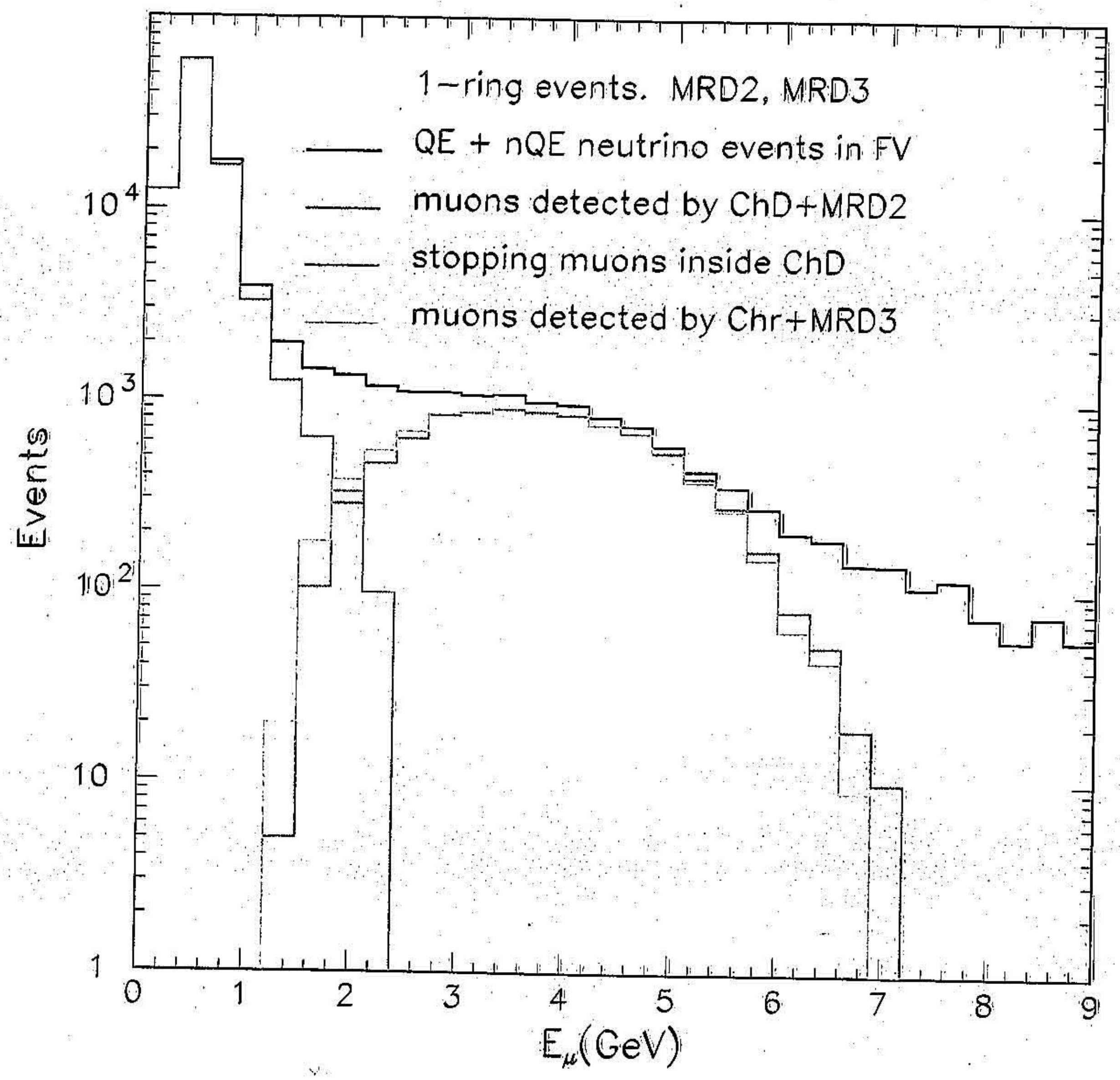
NEUTRINO EVENTS

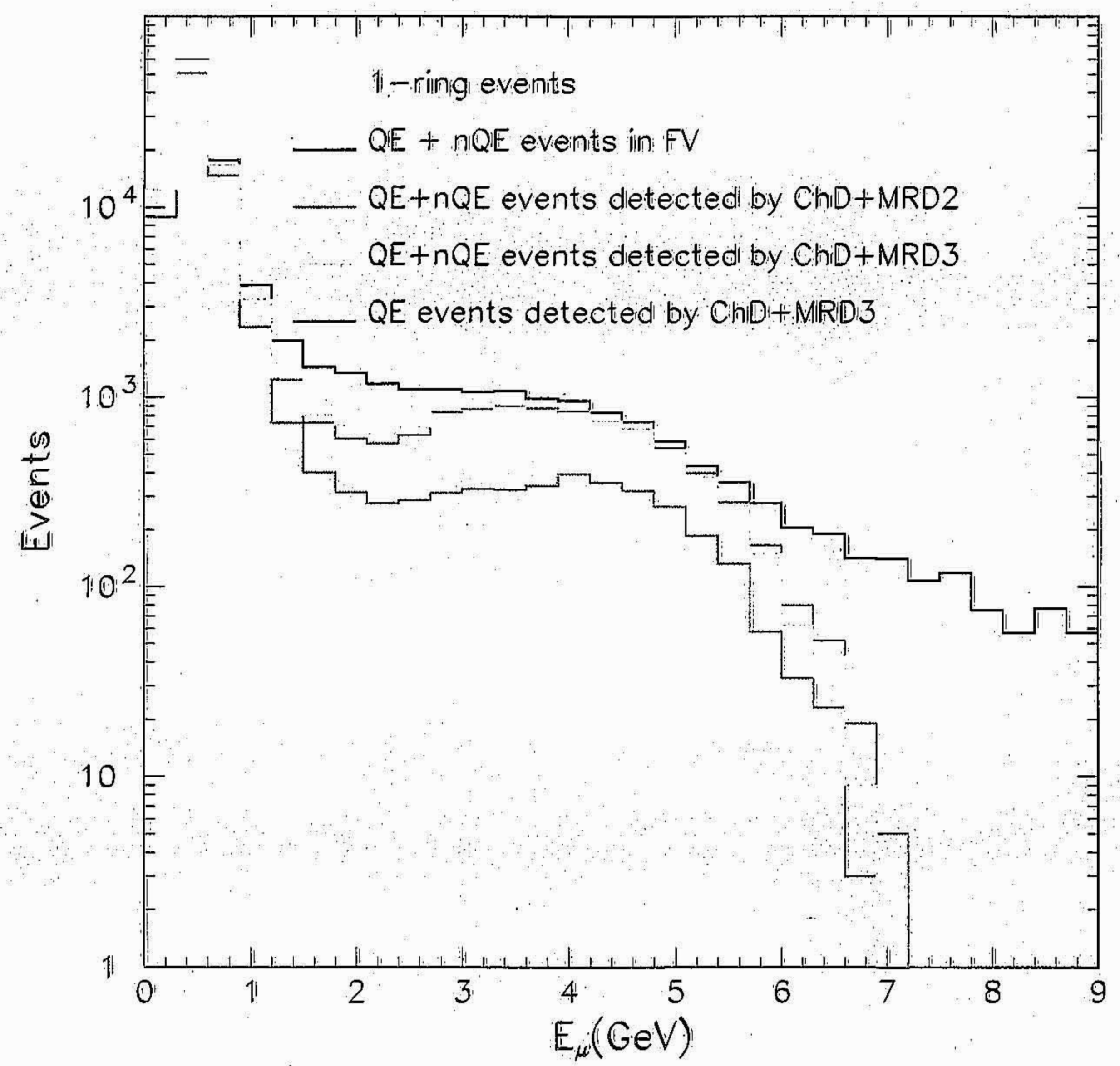
FV of Cherenkov Detector

	1ring	total
QE	85172	116766
QE+nQE	110445	213791
QE/nQE	3.5	1.2

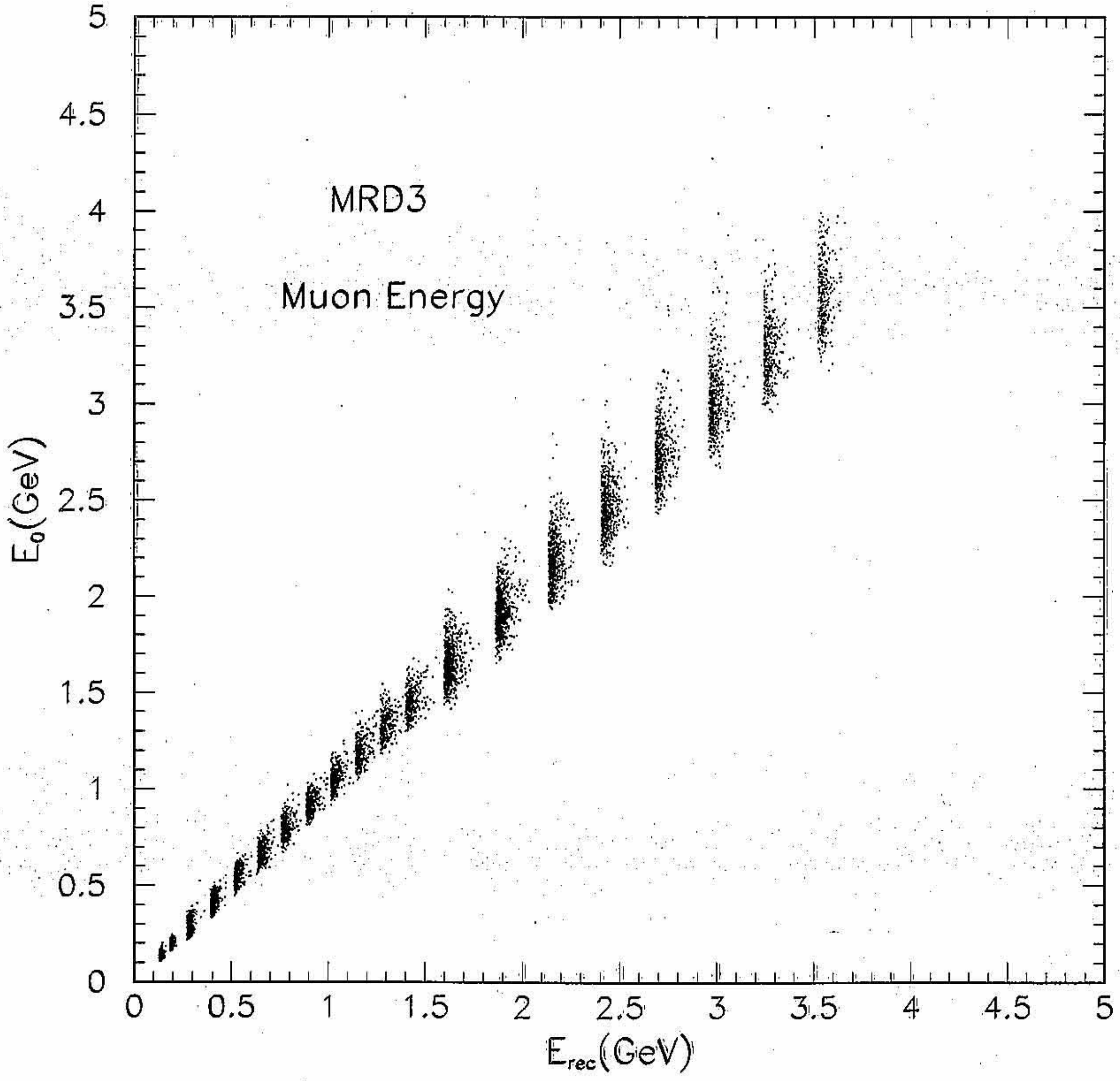
Cherenkov Detector + MRD

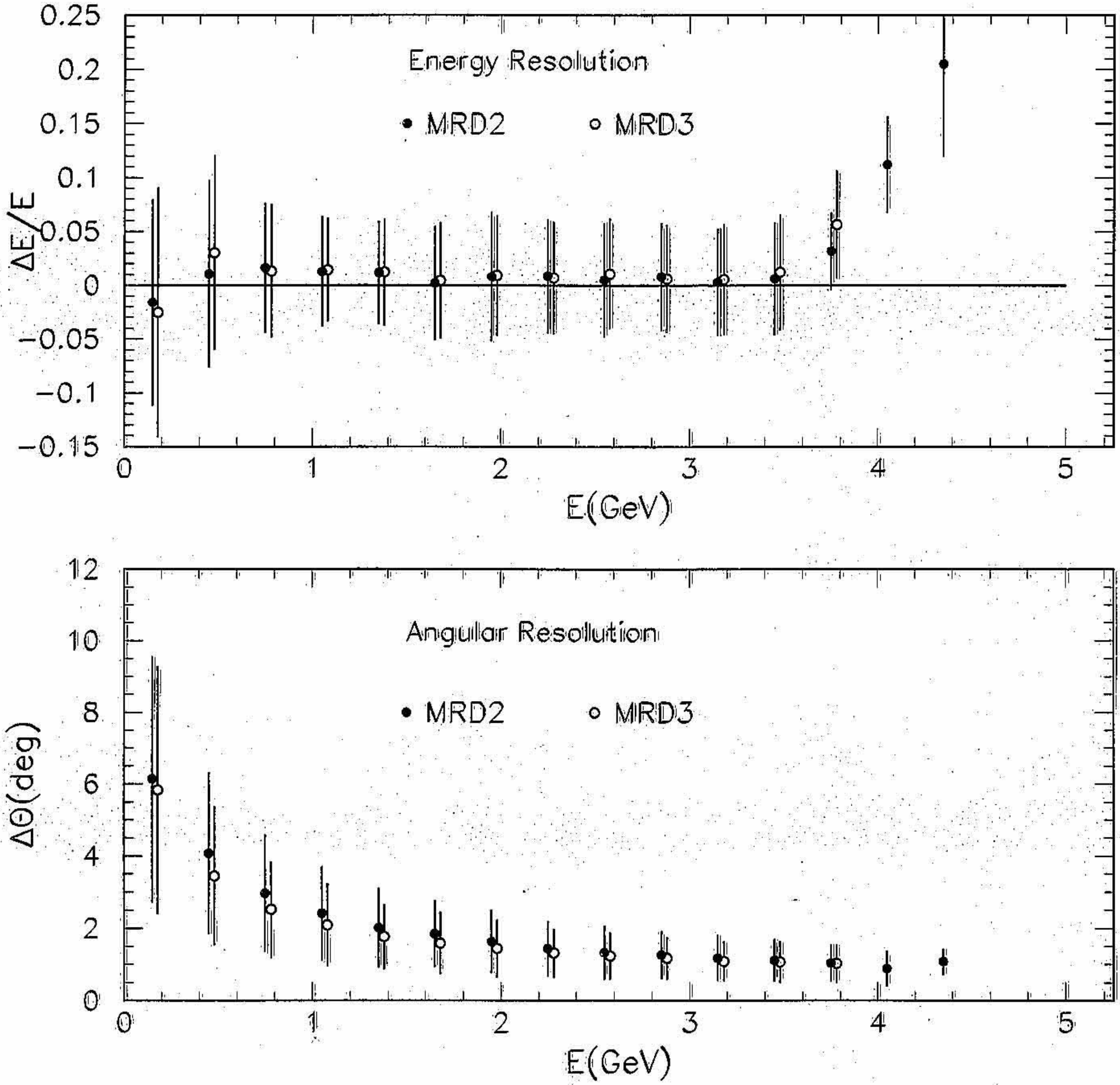
	1ring	total
QE	3847	5475
QE+nQE	9014	27014
QE/nQE	0.75	0.25


1−ring events. MRD2, MRD3
QE + nQE neutrino events in FV
muons detected by ChD+MRD2
stopping muons inside ChD
muons detected by Chr+MRD3
Events
10^4
10^3
10^2
10
1
0
1
2
3
4
5
6
7
8
9
E_μ(GeV)

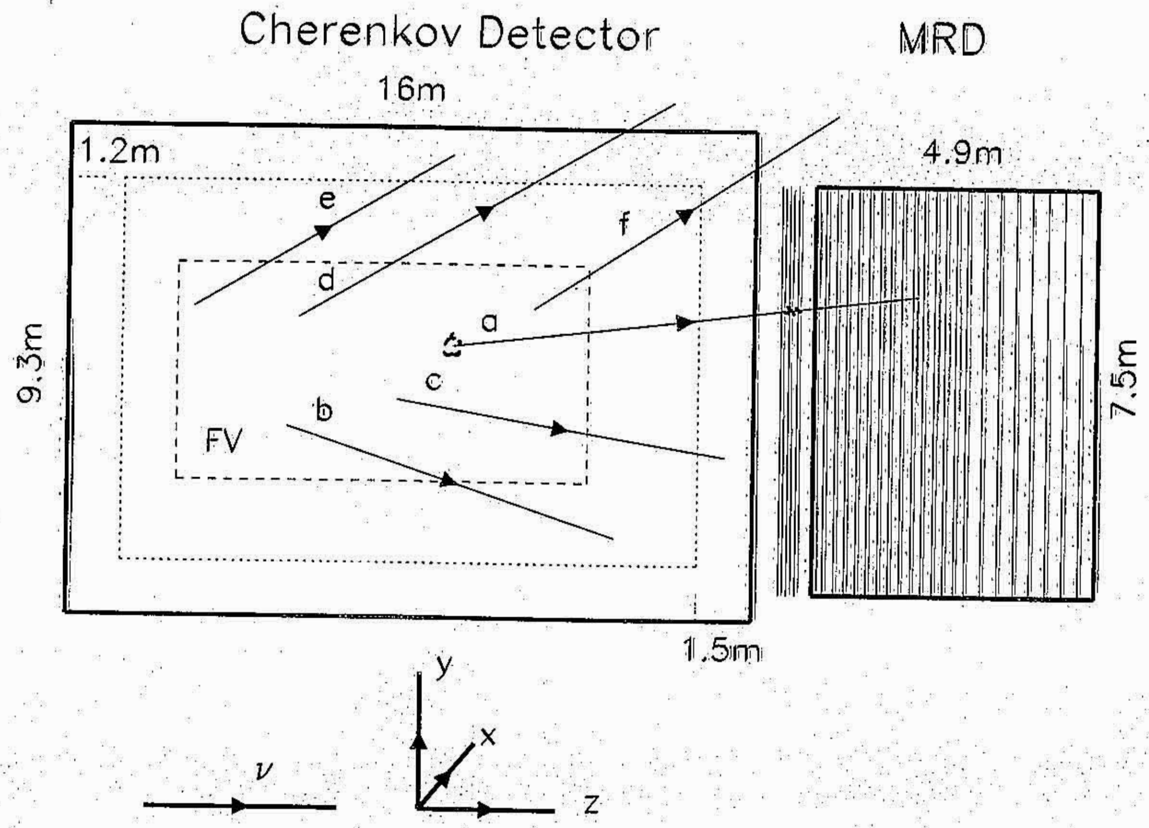


1-ring events
QE + nQE events in FV
QE+nQE events detected by ChD+MRD2
QE+nQE events detected by ChD+MRD3
QE events detected by ChD+MRD3
Events
10^4
10^3
10^2
10
1
0
1
2
3
4
5
6
7
8
9
E_μ(GeV)

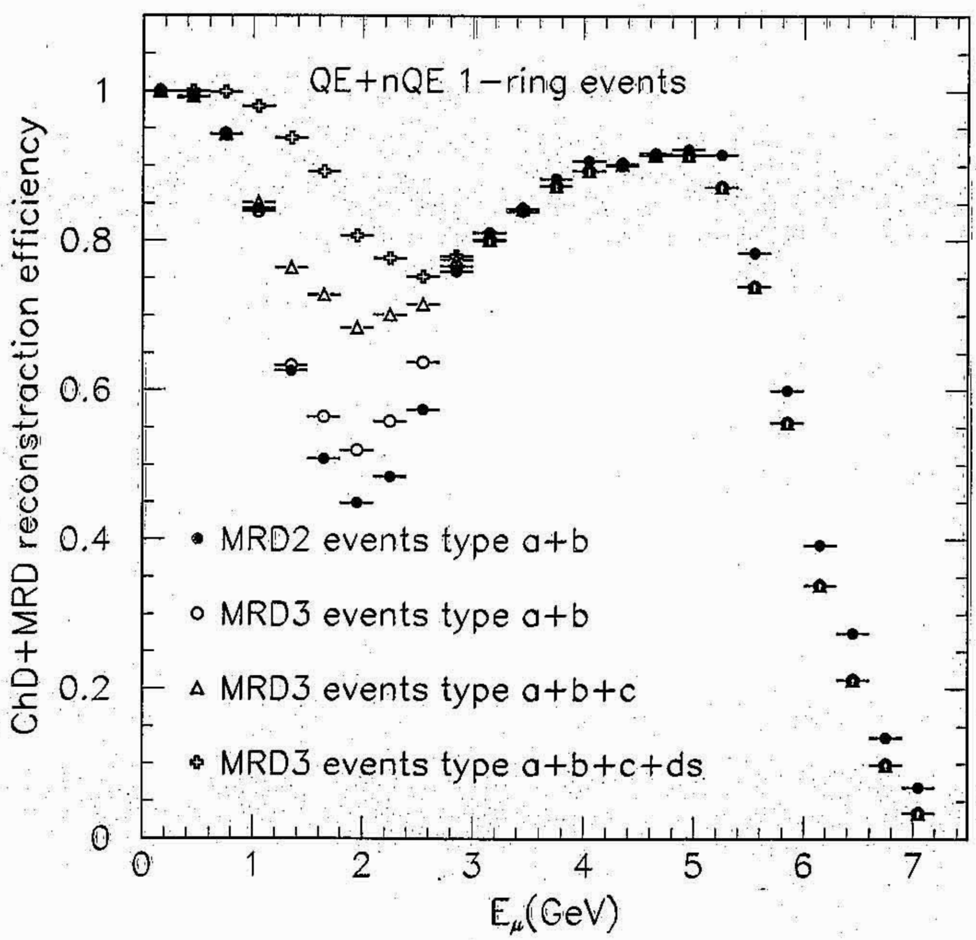

MRD3
Muon Energy
E_0(GeV)
E_{rec}(GeV)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5



Energy Resolution
MRD2
MRD3
ΔE/E
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
0
1
2
3
4
5
E(GeV)
Angular Resolution
MRD2
MRD3
ΔΘ(deg)
12
10
8
6
4
2
0
0
1
2
3
4
5
E(GeV)



Cherenkov Detector
MRD
16m
1.2m
4.9m
9.3m
7.5m
1.5m
FV
a
b
c
d
e
f
y
x
z
ν


QE+nQE 1−ring events
ChD+MRD reconstraction efficiency
E$_\mu$(GeV)
MRD2 events type a+b
MRD3 events type a+b
MRD3 events type a+b+c
MRD3 events type a+b+c+ds
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6
7

ChD&MRD: Muon energy reconstruction method

- Muon energy losed in MRD E_{MRD} is determined.

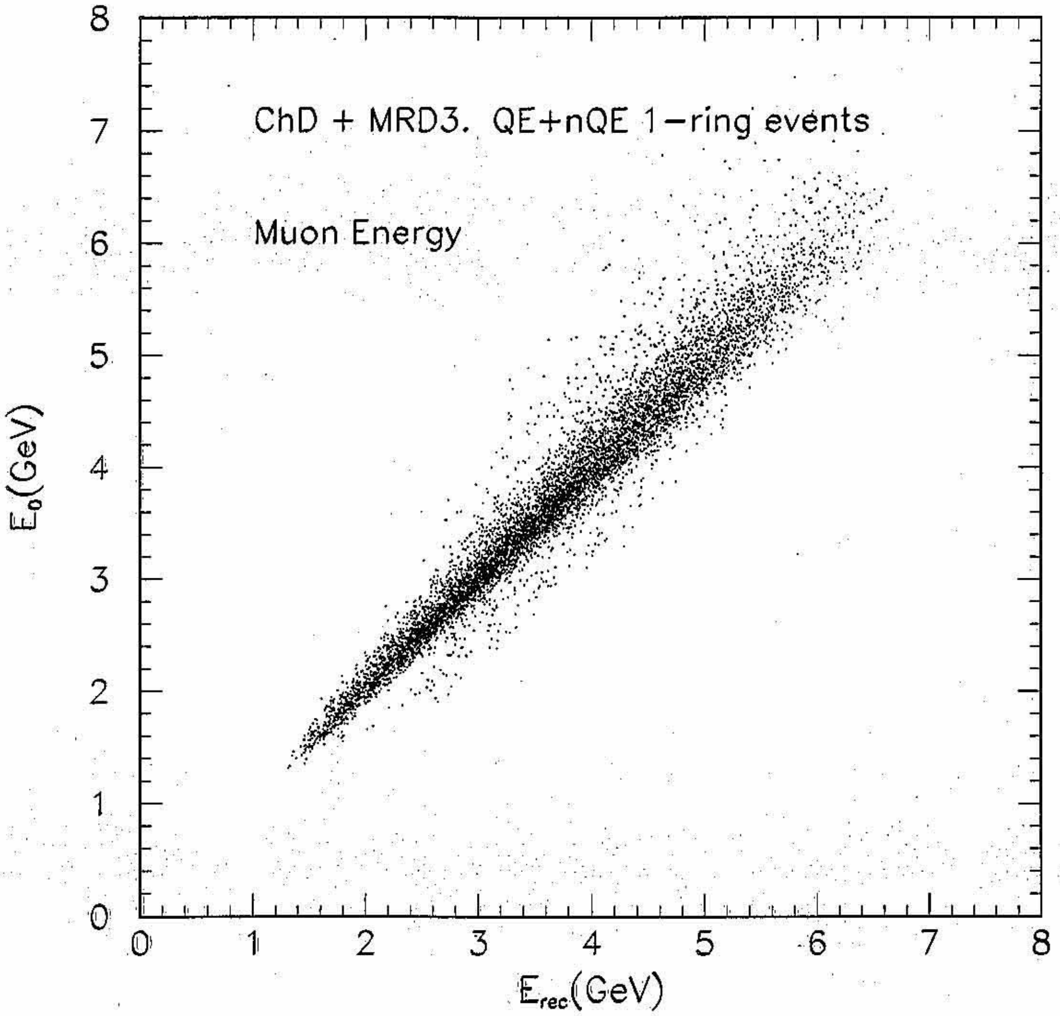
- Muon direction at the production is evaluated, using the reconstructed vertex position in the ChD and the coordinates of the hitted strips on stintillator planes between the ChD and MRD active regions

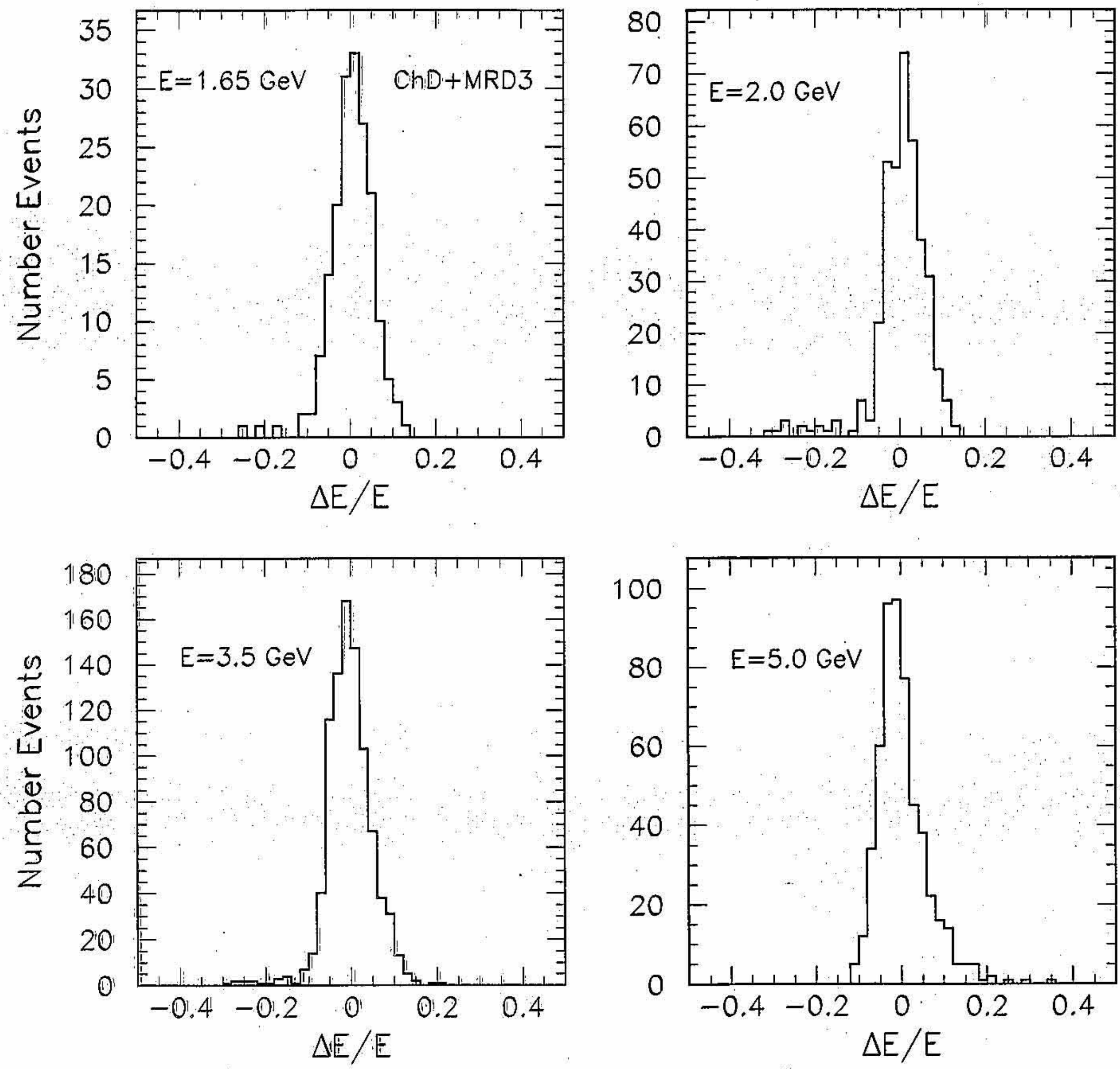
- Track length L_{ChD} in the ChD is calculated

- Energy losses in water dE/dX is fitted at the energy E_{MRD} and muon energy at the production is estimated as $E_i = E_{MRD} + (dE/dX)L_{ChD}$.

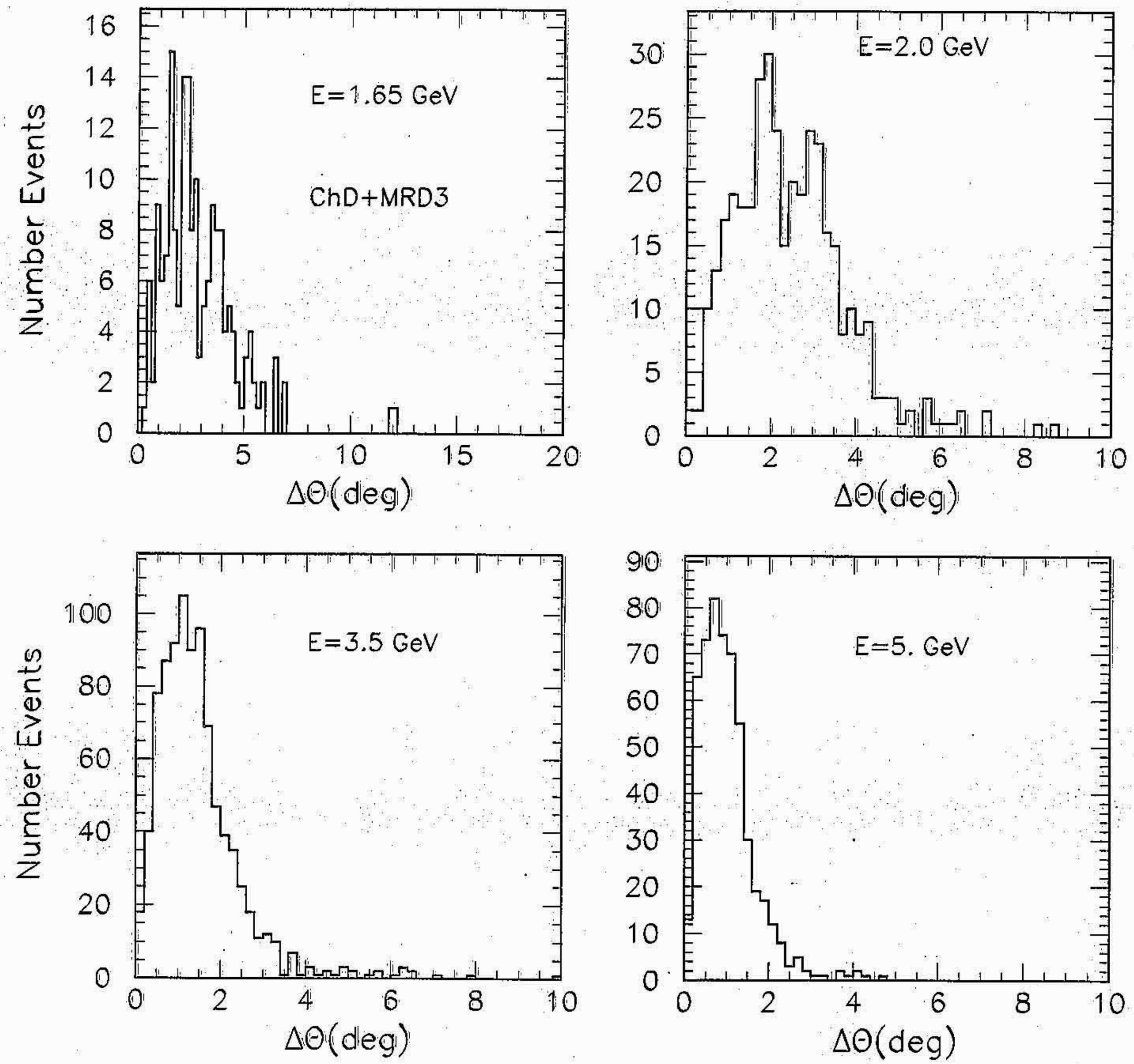
- dE/dX is fitted at energy $E_f = \sqrt{E_i E_{MRD}}$ and the muon energy E_{i+1} is evaluated.

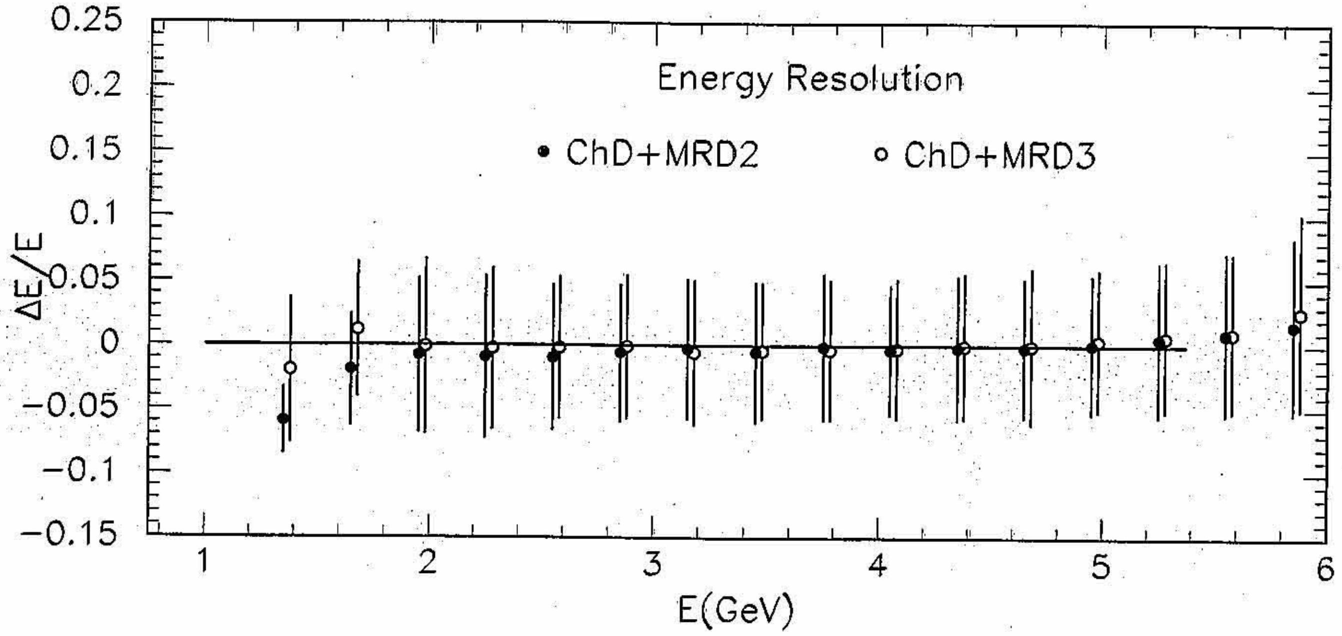
- Repeat until $\mid E_{i+1} - E_i \mid / E_{i+1} \leq 0.01$

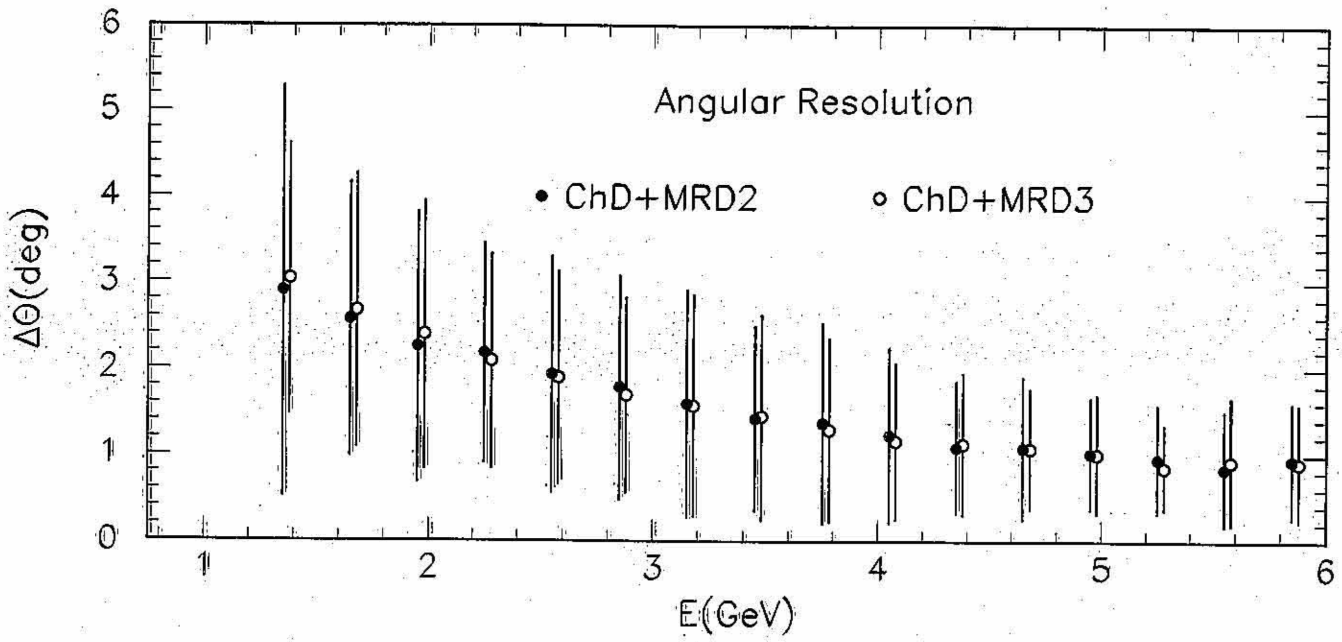

ChD + MRD3. QE+nQE 1-ring events
Muon Energy
E_0(GeV)
E_{rec}(GeV)
0
1
2
3
4
5
6
7
8

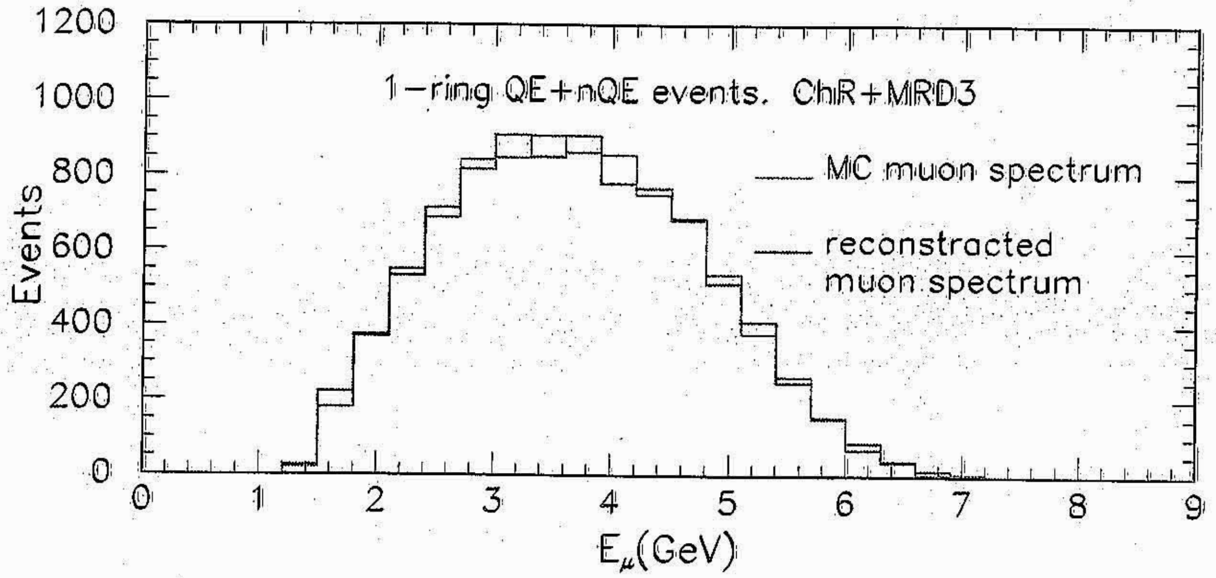


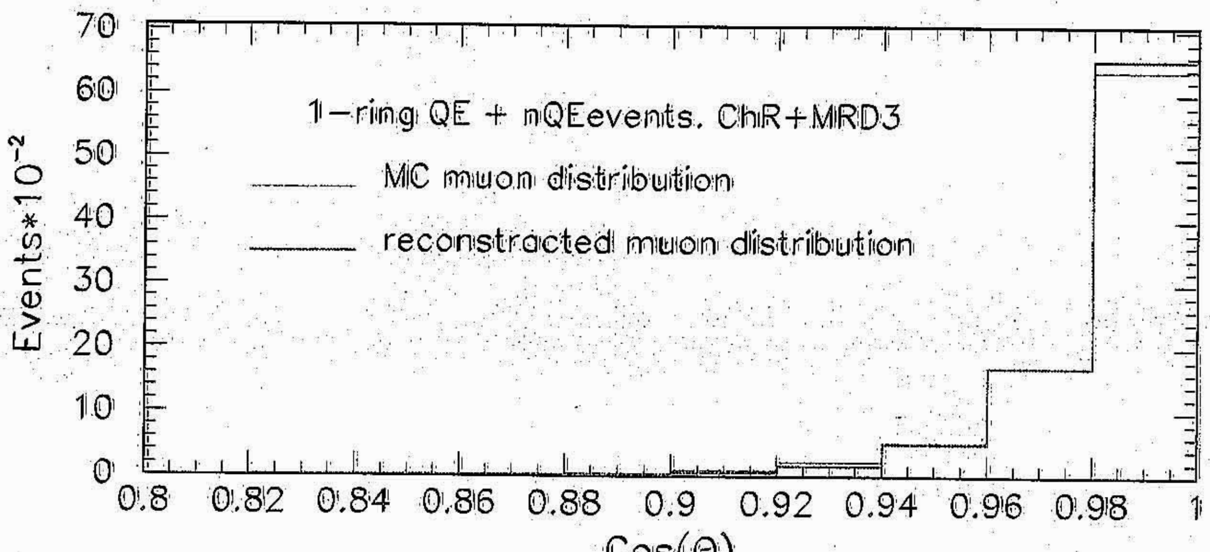
E=1.65 GeV
ChD+MRD3
E=2.0 GeV
E=3.5 GeV
E=5.0 GeV
Number Events
Number Events
ΔE/E
ΔE/E
ΔE/E
ΔE/E


E=1.65 GeV
ChD+MRD3
E=2.0 GeV
E=3.5 GeV
E=5. GeV
Number Events
ΔΘ(deg)


Energy Resolution
• ChD+MRD2
o ChD+MRD3
ΔE/E
E(GeV)


Angular Resolution
• ChD+MRD2
o ChD+MRD3
ΔΘ(deg)
E(GeV)


1−ring QE+nQE events. ChR+MRD3
MC muon spectrum
reconstracted
muon spectrum
Events
E_μ(GeV)
0
200
400
600
800
1000
1200
0
1
2
3
4
5
6
7
8
9


1−ring QE + nQEevents. ChR+MRD3
MC muon distribution
reconstracted muon distribution
Events*10^{-2}
Cos(Θ)
0
10
20
30
40
50
60
70
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1

Conclusion

MRD

- Energy acceptance of MRD is from 0.12GeV to 3.5GeV with a resolution $\sigma(\Delta E/E)$=5÷6%.

- Track angular resolution $\Delta\theta$ is about 1°÷5° and depends on muon energy .

Cherenkov detector + MRD

- Energy acceptance is 1.2 ÷ 6.0GeV with reconstarction efficiency $\varepsilon \geq 0.5$ for events detected in active regions of the ChD and MRD.

- The efficiency will be $\varepsilon \geq 0.75$ if an outer detector is used for detection of the stopping muons in the insensitive ChD region.

- Energy resolution $\sigma(\Delta E/E)$=5÷6%

- Track angular resolution $\Delta\theta$ decreases with energy from 3° up to 0.7°

Thanks!

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I'm looking forward for fruitful collaborations in JPARC-nu experiment in the future